Reflection and retroreflection

Types of reflection

When looking at a reflecting surface, the surface shows an image of the space in front of the surface.

The image may be complete blurred as in a surface with diffuse reflection, or it may be sharp as in surface with mirror reflection.

Most practical surfaces have mixed reflection, which is a mixture of diffuse reflection and mirror reflection in the surface, mostly with the surface reflection partly blurred by texture.

A particular kind of reflection is retroreflection, where the surface preferentially shows an image of the part of space around the observer. Retroreflection may be mixed with other kinds of reflection.

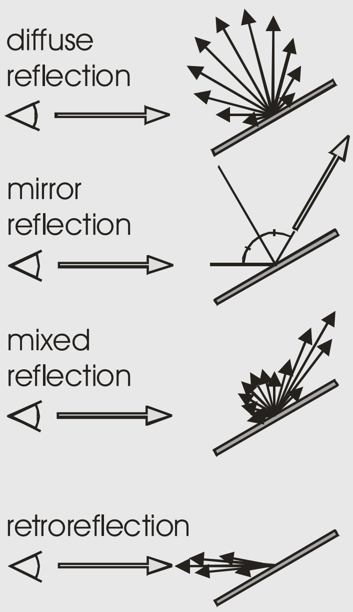

Figure 1: Types of reflection.

Characteristics for reflection

The image shown in a reflecting surface can maximum have the brightness of the part of space, which is shown as an image, but in practise the brightness is reduced because of reflection losses.

The physical measure of brightness of a surface is luminance L, which is the luminous intensity of light towards the drivers eyes in proportion to the apparent surface area of the surface. As the luminous intensity is measured in the unit of candela (cd) and surface area is measured in square metres (m^2), the unit of luminance is $cd \cdot m^{-2}$.

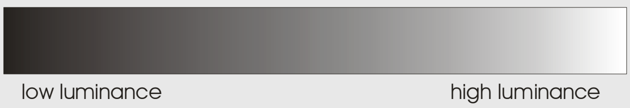

Figure 2: Luminance is the stimulus for the perception of brightness.

A surface with diffuse reflection has a luminance, which is a proportion of the average luminance of the space in front of the surface. The proportion is called the luminance factor with the symbol β or Y and is often measured in the 45°/0° geometry, implying illumination at 45° to the surface and observation perpendicular to the surface.

The luminance observed in a mirror is a proportion of the luminance of the object studied in the mirror image. In this case the proportion is called the reflectance, which is often measured at 8° entrance angle.

Mixed reflection can be described by means of a luminance coefficient, which is the ratio between the luminance of the surface and the illuminance at the surface. As illuminance is measured in lux (lx), the unit of the luminance coefficient is $cd \cdot m^{-2} \cdot lx^{-1}$. The conditions of observation and illumination are generally specified, because the

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value of the luminance coefficient may depend sharply on the conditions.

Retroreflection has a very useful effect for nighttime driving. A driver of a vehicle sees an image in a retroreflecting surface that includes the headlamps of the vehicle, and therefore is more bright than a surface with ordinary reflection.

Retroreflection is among else used to:

- enhance the brightness and visibility of the pavement markings
- greatly improve the brightness and readability of retroreflective road signs.

The luminance coefficient is applicable for a retroreflecting surface, but with the name of 'coefficient of retroreflected luminance':

$R_L = L/E$

where L is the luminance of the surface in illumination from a single light source

and E is the illuminance at the surface created by the light source and measured on a plane perpendicular to the direction of illumination.

Chromaticity of reflecting surfaces

The reflected light can have the same colour as the incident light, or it can have a different colour because of selective absorption of parts of the spectrum of light (or other phenomena).

The colour of reflected light is used to characterize the surface, when assuming particular spectral compositions of the incident light. The colour of the surface is expressed in terms of the CIE chromaticity coordinates x, y. Particularly relevant spectral compositions of the incident light are the CIE illuminant A, representing vehicle headlamps, and CIE illuminant D65, representing daylight (ISO/CIE 10526).

Pavement markings

Pavement markings are used to guide and regulate traffic by means of longitudinal and transverse markings, and by means of symbols and text on the pavement surface.

Pavement markings are provided by the application of materials in the liquid form (paint, thermoplastic materials or cold hardening materials), or by the application of pre-formed lines and symbols or by other means.

Retroreflection of pavement markings

Most pavement markings have glass beads embedded in the surface in order to create retroreflection.

These are added as drop-on beads during the application of materials in the liquid form, or during the production of pre-formed lines and symbols. Some materials have additional premix glass bead that are intended to replace the surface beads as the markings are eroded by the actions of traffic and weather.

The glass beads cause retroreflection in a three step process involving refraction (bending) as light enters a bead, reflection in the material in which the bead is embedded and refraction as the light leaves the bead.

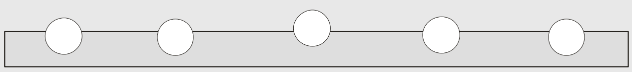

Figure 3: Glass beads in the surface of a pavement marking.

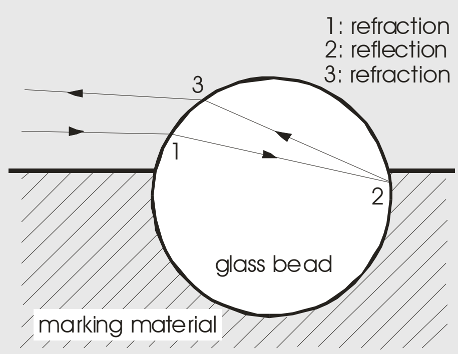

Figure 4: Three step process for retroreflection in a glass bead.

The glass beads provide poor focus and collimation and, therefore, cause retroreflection in a broad beam. This, in combination with several losses relating to the density of beads in the surface, variations in embedment, the reflection in the marking material, etc., causes a low level of retroreflection.

The coefficient of retroreflection R_L is used to characterize the retroreflection. Because of the low level of retroreflection, the one thousand times smaller unit of $mcd \cdot m^{-2} \cdot lx^{-1}$ (millicandela per square meter per lux) is used to provide convenient numbers instead of the full unit of $cd \cdot m^{-2} \cdot lx^{-1}$.

The retroreflected beam includes the drivers eyes at all relevant distances so that the value of R_L does not depend strongly on the distance. It does, for geometrical reasons, depend on the geometry of the vehicle, but in predictable manners.

For these reasons, an R_L value for a single geometrical situation is used to characterize the overall performance of a pavement marking, regardless of distance and vehicle geometry. This so-called 30 m geometry is normally explained for a driver of a passenger car, but does strictly speaking apply for a motorcyclist; it has been adopted in standards by the American ASTM (E1710), the European CEN (EN 1436) and in several national standards. The illumination is according to CIE illuminant A.

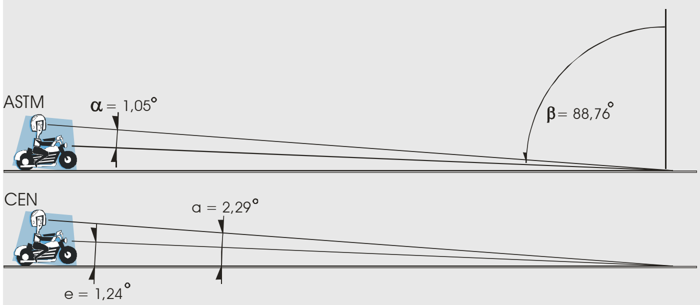

Figure 5: Angles defining the '30 m geometry' in ASTM and CEN standards.

R_L values of pavement markings are measured with hand-held instruments which, by means of optics, reproduce the 30 m geometry in a compact form. Measurement on panels by range instruments in laboratory conditions is defined (ASTM D4061 and EN 1436) and sometimes used, but is considered to be less developed than measurement with portable instruments.

New, white pavement markings with glass beads of normal glass have R_L values of for instance 300-400 $mcd \cdot m^{-2} \cdot lx^{-1}$. In some cases, glass beads made of glass with a high refractive index is used, causing R_L values that may be twice as high. New glass bead technologies may result in even higher values. Yellow pavement markings have inherently lower R_L values, for instance lower by 20%.

The R_L values typically decrease strongly during functional life with abrasion by wheels and actions of weather. The R_L value used for warranty purposes is often 100 $mcd \cdot m^{-2} \cdot lx^{-1}$.

In comparison, the pavement itself may have R_L values of 10 $mcd \cdot m^{-2} \cdot lx^{-1}$ for a dark asphalt concrete up to perhaps 40 $mcd \cdot m^{-2} \cdot lx^{-1}$ for a light asphalt concrete or cement concrete pavement.

In wet or rainy conditions, the surface of pavements markings may become covered by a film of water that makes the R_L values decrease strongly, in some cases to virtually zero.

In order to maintain some performance in wet or rainy conditions, the retroreflection is sometimes enhanced by special properties. The properties can be produced by surface texture (as with structured markings), large glass beads or other means. In the case of surface texture, the passage of wheels can produce acoustic or vibration effects.

Such pavement markings, when new, may have relatively high R_L values in wet or rainy conditions. However, these R_L values also typically decrease during functional life and may end up not being very high, often 25 to 50 $mcd \cdot m^{-2} \cdot lx^{-1}$, but still with contrast to the pavement with an R_L value of for instance 5 $mcd \cdot m^{-2} \cdot lx^{-1}$.

Daylight reflection of pavement markings

Daylight reflection of pavement markings is described by the luminance factor β (or Y) measured in the 45°/0° geometry and/or by the luminance coefficient under diffuse illumination Qd with observation as in the 30 m geometry. For both characteristics, illumination is according to the CIE illuminant D65.

The luminance factor is the traditional measure of daylight reflection. Values can be measured in laboratory conditions, but are normally measured with handheld instruments, which also measure the colour.

The luminance factor under diffuse illumination Qd is the more recent measure. The same unit of $mcd \cdot m^{-2} \cdot lx^{-1}$ as for the R_L is used to provide convenient numbers. Qd values are measured with handheld instruments.

Altogether, Qd may be considered a more realistic measure than β, because the observation is relevant for car driving and the illumination simulates daylight illumination - or an average road lighting. The correlation between the two characteristics is poor, because:

- Qd includes only the top of the pavement surface as seen by the drivers at a distance while β includes the whole depth including the bottom
- Qd includes surface reflection, which is excluded from β.

The two characteristics have been adopted by the American ASTM (D6628 and E2302), the European CEN (EN 1436) and in national standards. They are used sometimes in a complementary or alternative manner, or sometimes one is preferred to the other.

The theoretical maximum value of β is unity, while the theoretical maximum value of Qd is $1000/\pi$ = approximately 318 $mcd \cdot m^{-2} \cdot lx^{-1}$.

For white pavement markings,values are typically up to β = 0,6 or Qd = 200, but can sometimes get low when dirt and oil stick to the surface. For yellow pavement markings values are somewhat less.

Colour of pavement markings

The colour of pavement markings is expressed in terms of the CIE chromaticity coordinates x, y as measured in the same conditions as for the luminance factor β. Handheld instruments are used to measure all three parameters (β, x and y) simultaneously.

The chromaticity coordinates are normally to be within specified colour boxes defined for white and yellow pavement markings by the American ASTM (D6628), the European CEN (EN 1436) or national standards. Some national standards specify colour boxes for other colours such as orange, red, green and blue.

Generally speaking, colours measured in β conditions are - for a number of reasons - more saturated than in real driving situations in which white and yellow pavement markings can not always be easily distinguished from each other.

Such cases are exposed if chromaticity coordinates are measured in the conditions of R_L and Qd for respectively nightime and daytime driving. The American ASTM has defined colour boxes for white and yellow measured in R_L conditions (D6628) and is working on suitable methods for the measurement of colour in both R_L and Qd conditions (WK 358 and WK2310).

Road signs

Road signs are used extensively to guide and regulate traffic in the form of directional signs, tourist signs, warning signs, prohibition signs, background signs etc.

Retroreflection of road signs

Almost all road signs are retroreflective in order to be visible and readable at night in vehicle headlamp illumination. The sign face itself is formed by retroreflective sheetings, either in overlay, or with coloured overlay films, or screen printing, to form a background with one or more legends, and sometimes an edge.

The retroreflective sheetings may be based on the glass bead technology, or they may be microprismatic.

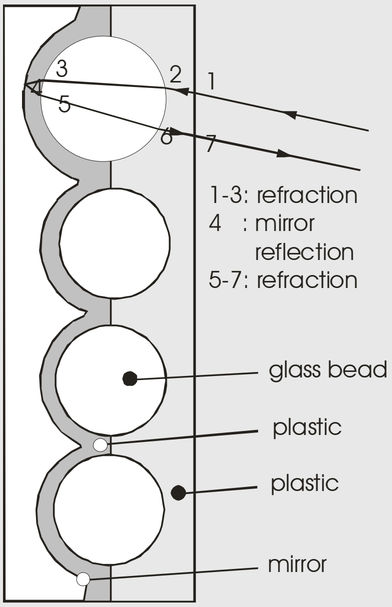

Figure 6: A glass beaded sheeting of the enclosed lens type.

Some glass beaded sheetings have glass beads enclosed in plastic, while other glass beaded sheetings have glass beads encapsulated behind a plastic layer, but otherwise suspended in air. The two principles are called respectively enclosed an encapsulated lens.

The process of retroreflection of glass beaded sheetings involves refraction and reflection. The process is basically the same as for glass beads in pavement markings, but focus and collimation is far better and losses are less. Therefore, retroreflection is much in a much more narrow beam and stronger than for pavement markings.

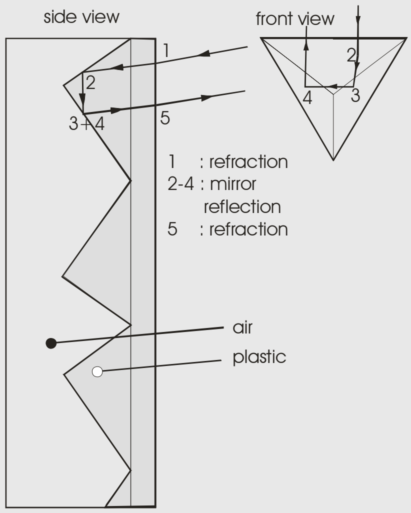

*Figure 7: A microprismatic sheeting***.**

The process of retroreflection in microprismatic sheetings is entirely different than for glass beaded sheetings, involving mirror reflections (by total reflection in the plastic-air interface) in three mutually orthogonal surfaces that are backsides of prisms. Additionally, there is refraction as light enters and leaves the plastic medium in which the prisms are formed. This allows retroreflection in a beam that can be even more narrow than for glass beaded sheeting materials.

The conventional measure of retroreflection of a retroreflective road sign is the coefficient of retroreflection R_A, which has a somewhat different definition than the coefficient of retroreflected luminance R_L. The connection between the two is given by $R_A = R_L \times \cos\beta$, where β is the entrance angle of the light incident on the road sign. The unit used for R_A is $cd \cdot lx^{-1} \cdot m^{-2}$.

Due to the narrowness of the retroreflected beam, the R_A value depends on of the observation angle α, which measures the angular location of the drivers eyes relative to centre of the retroreflective beam. The R_A value generally decreases with increasing α, this corresponding to a decrease as a driver approaches a road sign. This causes the remarkable feature that the luminance of a road sign often stays roughly constant over a range of distances during approach.

Additionally, the R_A value has a dependence on the entrance angle β.

Because of these dependencies, specifications for road signs are provided as minimum R_A values in tables with α and β as parameters. ASTM (D 4956) distinguishes between two types of the enclosed lens, one type of encapsulated lens, and several types of microprismatic sheetings, enumerating these as I, II, III etc. CEN (EN 12899-1) presently defines only one type of enclosed lens and one type of encapsulated lens.

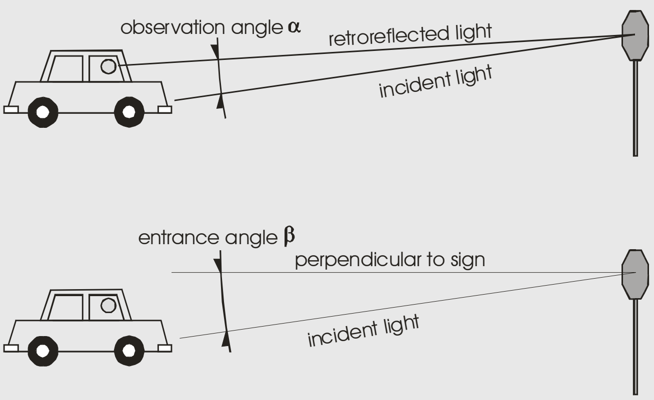

Figure 8: Observation angle α and entrance angle β.

NOTE 1: It does require two more angles in addition to α and β to specify the geometrical situation completely.

For glass beaded sheetings, a possible variation of the R_A values with the additional angles is normally ignored by keeping all relevant axes in the same vertical plane during measurement.

For microprismatic sheetings, the variation of the R_A values with the additional angles may be fairly strong. There are different approaches regarding variation of these angles during complete testing.

Complete testing to verify compliance with specifications is done by range instruments on samples in laboratory conditions. Other testing is done with handheld instruments in the field or on samples at single geometries defined in standards by the American ASTM (E1709) and the European CEN (EN 12899-1). Handheld instruments simulate long distances, but are reduced to compact form by means of optics.

NOTE 2: Handheld instruments are to be held upright for normal measurement. Rotation from this position does not change the reading significantly for glass beaded sheetings, but does change the reading for most types of microprismatic sheetings.

White parts of road signs have R_A values in these geometries in tens or hundreds of $cd \cdot lx^{-1} \cdot m^{-2}$, depending on the type of the retroreflective sheeting. This is a testimony to the efficiency of retroreflection, as the maximum R_A value of a diffuse reflecting surface is only $1/\pi$ equal to approximately 0,3 $cd \cdot lx^{-1} \cdot m^{-2}$.

Coloured parts of road signs have smaller R_A values than white parts to a degree depending of the colour.

The R_A values of road signs eventually degrade with exposure to weather, abrasion by particles and other actions. Handheld instruments are used among else to decide warranty issues and need for replacement.

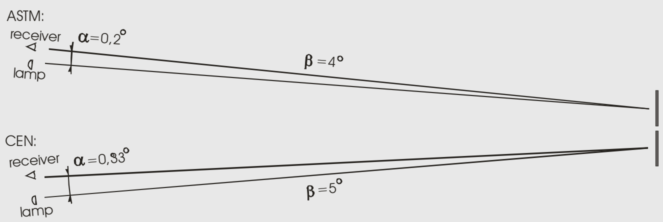

Figure 9: Geometries used for handheld R_A instruments according to ASTM and CEN.

NOTE 3: ASTM E1709 allows an 'annular' receiver for handheld instruments in addition to the 'point' receiver of the same principle as used for the range instruments. Handheld instruments with these two types of receivers provide different readings for some of the types of microprismatic sheetings.

Daylight reflection and colour of road signs

The colour of road signs is expressed in terms of the CIE chromaticity coordinates x, y as measured in the same conditions as for the luminance factor β. Handheld instruments are used to measure all three parameters (β, x and y) simultaneously.

The chromaticity coordinates are normally to be within specified colour boxes defined for different colours by the American ASTM D4956), the European CEN (EN 12899-1) or national standards.

These chromaticity coordinates represent daytime conditions. For nighttime conditions, the chromaticity coordinates change because of the change of illuminant (from daylight represented by CIE illumninant D65 to headlamps represented by CIE illuminant A). Additional changes may be invoked because of optical phenomena like diffraction in the small retroreflective elements.

For this reason, the American ASTM (E811) has defined a test method for nighttime chromaticity. So far, handheld instruments have not been equipped with this facility, and measurements are to be performed in laboratory conditions.

Standards for colorimetry:

ISO/CIE 10526: CIE standard illuminants for colorimetry

Standards for pavement markings:

EN 1436 Road marking materials - Road marking performance for road users

E1710 Standard Test Method for Measurement of Retroreflective PavementMarking Materials with CEN-Prescribed Geometry Using a Portable Retroreflectometer

E2302 Standard Test Method for Measurement of the Luminance Coefficient Under Diffuse Illumination of Pavement Marking Materials with CEN-Prescribed Geometry Using a Portable Reflectometer

D4061 Standard Test Method for Retroreflectance of Horizontal Coatings

D6628 Standard Specification for Color of Pavement Marking Materials

WK358- Test Method for Measurement of Nighttime Chromaticity of Pavement Marking Materials Using a Portable Retrocolorimeter

WK2310- Test Method for Measurement of Daytime Chromaticity of Pavement Marking Materials Using a Portable Reflectocolorimeter

Standards for road signs:

EN 12899-1 Fixed, vertical road traffic signs - Part 1: Fixed signs

E810 Standard Test Method for Coefficient of Retroreflection of Retroreflective Sheeting Utilizing the Coplanar Geometry

D4956 Standard Specification for Retroreflective Sheeting for Traffic Control

E1709 Standard Test Method for Measurement of Retroreflective Signs Using a Portable Retroreflectometer

E811 Standard Practice for Measuring Colorimetric Characteristics of Retroreflectors Under Nighttime Conditions